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STUDIES OF THE CLEARING PHASE IN  
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**ANNUAL REPORT  
NASW-4756**

***"Observational Studies of the Clearing  
Phase in Proto-Planetary Disk Systems"***

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Annual Report for NASW - 4756:  
Observational Studies of the Clearing Phase in Proto-Planetary Disk Systems

for the period March 19, 1994 - March 18, 1995.

Work on NASW-4756 during the second year is summarized below. Since we have been reporting the progress on a quarterly basis, results from the first 9 months are summarized briefly. Work during the last quarter, which has not previously been reported, is discussed in more detail.

**1. Recent Observations:** IUE Hot star observations in support of the WUPPE science team on Astro-2 have been completed on March 15, 1995 with a total of 64 hours of observing time scheduled during the Astro-2 mission. In addition to classical Be stars, LBVs, and other hot star targets of interest to the WUPPE team, IUE observations of 7 Herbig Ae/Be stars have been obtained as part of program ASRKB. Quick-look analysis of one of the stars, HD 100546, showed spectacular accreting gas profiles visible to +400 km/s. Monitoring of the Herbig Be star HD 50138 in the mid-UV on a daily basis continues with IUE through March 27 as part of IUE program BWRCG. ISO phase II proposal planning for approved ISO program HAE2BPIC was completed at IPAC during the week of March 6-11.

**2. Survey of PMS Intermediate-Mass Proto-planetary Disk Systems:** The first quarter of 1995 marks the completion of IUE data acquisition for the Herbig Ae/Be stars with the end of the 17th/18th episode survey program and acquisition of spectra of a number of previously observed stars in support of the WUPPE science team program on Astro-2. As a result of this survey the IUE archive now contains observations of 64 Herbig Ae/Be stars and related objects, including high dispersion spectra of 40 stars. We find that accreting, circumstellar gas is seen in spectra of 38% of the stars. This detection fraction is appreciably lower than the 85% seen toward lower-mass PMS stars (Edwards et al. 1994). Velocities in the range 100-400 km/s are routinely observed, show no obvious correlation with stellar mass, but instead appear to be correlated with the IR excess, and are consistent with detection of material in free-fall toward the PMS stars. Collisionally ionized plasma is routinely observed in the spectra of the stars with accreting gas, as are absorption components similar to those seen toward  $\beta$  Pic.

Lynne Hillenbrand (UMASS, UC Berkeley) has graciously made available to us unpublished  $v \sin i$  data for a number of our program stars, enabling us to demonstrate that the stars with accreting gas have systematically higher  $v \sin i$  values than stars with spectra showing outflows. The association of accretion with high  $v \sin i$  and polarimetric variability strongly suggests that the accreting material in the Herbig Ae/Be stars is closely confined to the equatorial regions of these systems, unlike the T Tauri stars where accretion signatures are seen at high polar latitudes. Our data, therefore suggest that magnetically channelled accretion is unlikely to be effective in the

inner disks of these stars. The presence of material in the equatorial plane which is in free-fall suggests that the central regions of these disks are substantially cleared, confirming the interpretation of the IR spectral energy distributions of Hillenbrand et al. (1992). The available data suggest that accretion from flattened disk envelopes, such as has been modelled by Calvet et al. (1994), is plausible for these stars. Now that the data are in hand, a paper summarizing these results is in preparation.

**3. A Shell Stars:** In a parallel effort we have re-examined the main sequence A-shell star data available in the IUE archives. These stars occupy the same region in spectral type and  $v \sin i$  as the Herbig Ae stars with accreting gas. Accreting gas, visible to  $+100$  km/s is routinely observed in these objects, although with lower column densities than are seen in the  $\beta$  Pic system. Analysis of the IRAS source detections for these stars suggests that none of the other stars has an IR excess in the 12 micron region as large as  $\beta$  Pic. The available data suggest that  $\beta$  Pic is not unique in exhibiting variable, accreting gas. Recent work by Heap and collaborators suggests that  $\beta$  Pic is at most a ZAMS star. In this case, the other A-shell stars with accreting gas can plausibly be interpreted as somewhat older main sequence systems experiencing gradually diminishing accretion activity. A poster paper on these stars was presented at the January 1995 AAS meeting and a paper for the refereed journals is in preparation.

**4. Observation Planning:** The PI is collaborating with Bruce Woodgate (NASA/GSFC) in a program of coronagraphic imaging of PMS disk systems to be carried out with the Space Telescope Imaging Spectrograph (STIS) as part of the GTO program for the 2nd Generation HST science instruments. We anticipate that up to 4 systems may be imaged as part of the GTO program, with additional observations planned as part of a cycle 7 GO proposal. A presentation on this program was made at the STIS team meeting February 9-10, 1995 at GSFC. In a parallel effort, the PI is collaborating with Mark Clampin (STScI), Bruce Woodgate, Sally Heap, and Steve Maran (NASA/GSFC) in a planet search program to be supported as a STIS team internal key project with observing time contributed from the STIS GTO program.

**6. Papers and Talks:** The PI gave a colloquium on the Herbig Ae/Be star survey results on February 16 at the University of Massachusetts. A revised paper on UX Ori was submitted to A&A in mid-January 1995.

#### **Publications To Date:**

##### A. Refereed:

1. Grady, C.A., Bjorkman, K.S., Shepherd, D., Schulte-Ladbeck, R.E., Pérez, M.R., de Winter, D., and Thé, P.S. 1993, "Detection of Accreting Gas Toward HD 45677: A Newly Recognized, Herbig

Be Proto-Planetary System" , *ApJ (Letters)*, 415, L39.

2. Brown, T., Buss, R., Jr., Grady, C., Bjorkman, K., Schulte-Ladbeck, R., 1995, "The Growth of Solids and Radiation Shielding in the Young Stellar Disk of HD 45677", *ApJ (Letters)* to appear February 20, 1995.

3. Grady, C.A., Pérez, M.R., Thé, P.S., Grinin, V.P., de Winter, D., Johnson, S.D., Yusef-Zadeh, F., Talavera, A., Blondel, P.F.C., Tjin A Djie, H.R.E., Calvet, N. 1995, "The  $\beta$  Pictoris Phenomena Among Young Stars. II. Ultraviolet Observations of the Herbig Ae Star UX Ori", *A&A* (submitted, and currently undergoing revision per referee report).

4. Grady, C.A., Pérez, M.R., and Talavera, A. 1995, "The  $\beta$  Pictoris Phenomenon in A-Shell Stars", (in preparation, submission to *ApJ (Letters)* planned for early 1995. )

#### B. Conference Proceedings:

1. Grady, C.A., Pérez, M.R., de Winter, D., and Thé, P.S., Yusef-Zadeh, F., and Johnson, S.D. 1993, "Detection of a Bipolar Flow Associated With UX Ori: An Intermediate Mass Pre-Main Sequence Star", to appear in *"Frontiers of Space and Ground-based Astronomy: The Astrophysics of the 21st Century"*, editors, M. Longair, W. Wamsteker, and Y. Kondo (Dordrecht: Kluwer) (in press).

2. Grady, C.A., Pérez, M.R., Thé, P.S., de Winter, D., Yusef-Zadeh, F., Johnson, S.D., and Grinin, V.P. 1993, "Low Dispersion UV Spectral Variability in 3 Herbig Ae Stars Viewed Through Their Circumstellar Proto-Planetary Disks", *BAAS* 25, 905.

3. Grady, C.A., Pérez, M.R., and Thé, P.S. 1993, "HD 45677 and HD 50138: Identification of 2 B[e] Stars as Herbig Be Stars Viewed Through Their Circumstellar Disks", in *The Nature and Evolutionary Status of Herbig Ae/Be Stars*, eds. P.S. Thé, M.R. Pérez, E.J. van den Heuvel, ASP Conference Series, 62, 409.

4. Grady, C.A., Pérez, M.R., Talavera, A., Thé, P.S., de Winter, D., Grinin, V.P., Calvet, N., 1993, "Iron Emission Lines in the Spectra of Herbig Ae/Be Stars Viewed Through Their Proto-Planetary Disks", *BAAS*, 25, 1353.

5. Brown, T., Buss, R.H., Grady, C., Bjorkman, K., Schulte-Ladbeck, R., 1993, "The Growth of Solids and Radiation Shielding in the Young Stellar Disk of HD 45677", *BAAS* 25, 1353.

6. Pérez, M.R., Grady, C.A., Blondel, P.F.C., de Winter, D., Thé, P.S., 1993, "Lyman  $\alpha$  as an Accretion Diagnostics in Young Stellar Objects", *BAAS* 25, 1352.

7. Grady, C.A. 1995, "The  $\beta$  Pictoris Phenomenon in Herbig Ae/Be Stars: UV Observations", in *Circumstellar Dust and Planet Formation*, eds. R. Ferlet and A. Vidal-Madjar (Paris: Editions Frontières) (In press, to appear early 1995).
8. de Winter, D., Grinin, V.P., Grady, C.A., Tambovtseva, L.V., Pérez, M.R., Thé, P.S., van den Ancker, M.E., Rostopchina, A.N. 1995, "The  $\beta$  Pic Phenomenon of the Herbig Ae: UX Ori", in *Circumstellar Dust and Planet Formation*, eds. R. Ferlet and A. Vidal-Madjar (Paris: Editions Frontières) (in press, to appear early 1995).
9. Sitko, M.L., Grady, C.A., Hanner, M.S., Lynch, D.K., and Russell, R.W. 1995, "Silicate Emission in Herbig Ae/Be Stars and Post-Herbig Ae/Be Stars - Relation to Cometary Dust", in *Circumstellar Dust and Planet Formation*, eds. R. Ferlet and A. Vidal-Madjar (Paris: Editions Frontières), (in press, to appear early 1995).
10. Grady, C.A., Pérez, M.R., and Talavera, A. 1994, "The  $\beta$  Pictoris Phenomenon in A-Shell Stars", BAAS (in press).



## Report Documentation Page

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16. Abstract Progress in "Observational Studies of the Clearing Phase in Proto-Planetary Disk Systems" is summarized for the second year of the study. An extensive program of high dispersion UV spectral studies using the International Ultraviolet Explorer (IUE) has resulted in acquisition of 40 Herbig Ae/Be star and related object spectra. We find that accreting, circumstellar gas is detected with velocities consistent with material in free-fall toward the stars in approximately 38% of the sample. With acquisition of optical measurements of the projected stellar rotational velocities, we find that the systems with accreting gas exhibit systematically higher projected rotational velocities than the systems showing signatures of outflowing material only. When combined with polarimetric and photometric data, the IUE spectra for these stars indicate that accretion in intermediate-mass pre-main sequence stars is confined to the plane of the circumstellar dust disk. This is in contrast to lower-mass PMS stars where accretion, presumably along magnetic field lines, is seen at polar latitudes. Our data also support significant clearing of the central regions of these circumstellar disks, as originally suggested by Hillenbrand et al. (1994). The model which most closely matches the observational data is accretion from a disk envelope, as developed by Calvet et al. (1994).			
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